PLEASE CLICK ON THE FOLLOWING LINK TO WATCH THE LECTURE ONLINE:-

https://www.youtube.com/watch?v=MltQoh1HC5A&list=PLuBRb5B7fa_eyBVgz4xb_AqlGcXLIEyRA&index=14

BASICS IN NONUNION

BY LAITH AL HSEINAT

Outlines :

- Epidemiology
- Bone healing
- Definition of Nonunion
- Pathophysiology
- Risk factors for the development of a nonunion
- Evaluation and Diagnosis
- General treatment principles

A 30 yr old male pt , MF , smoker ; sustained a closed femoral shaft fracture after falling from his horse .
Fixed by IM nail , 14 months the pt continue complaining of pain and weakness of his limb

NONUNION

- < 2% ; Males ; 25-45 yrs
- Biology : Diabetes (X7 folds)
- Tibia 5% ; clavicle 5% ; humerus 3%
- Diagnosis : ¾ cortices(rabbits!); RUST (4/16)
- Treatment concepts: ”Diamond” ; ‘’5 pillars ‘’ ; Calori (NUSS)

November 16, 2016

Epidemiology of Fracture Nonunion in 18 Human Bones

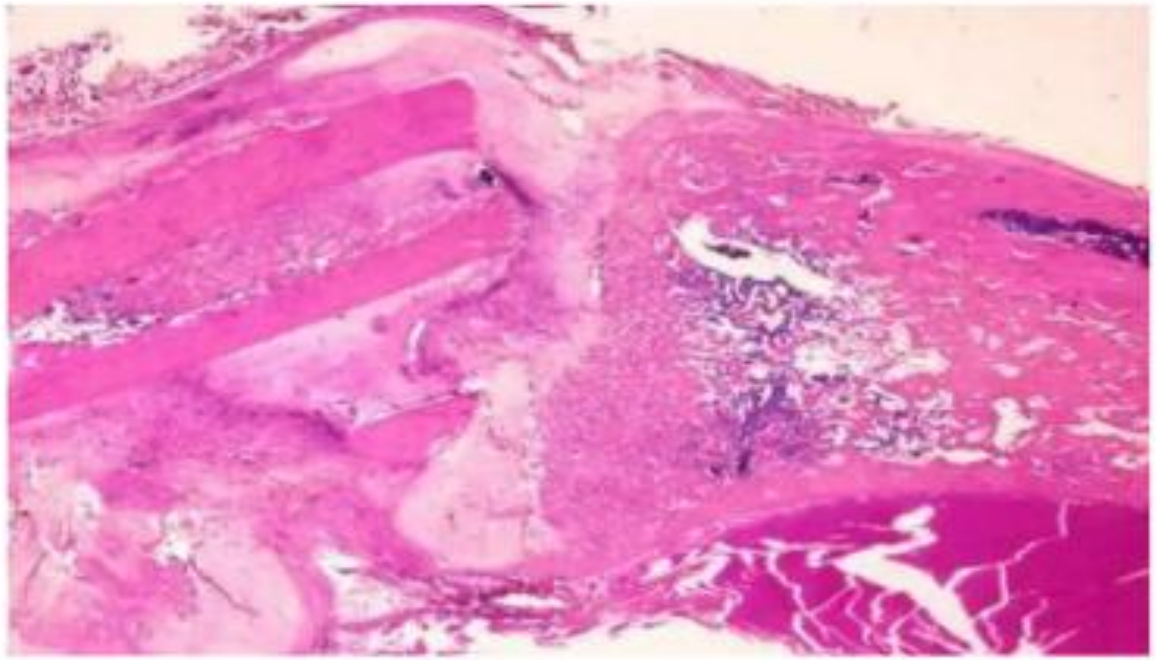
Robert Zura, MD[1]; Ze Xiong, MS[2]; Thomas Einhorn, MD[3]; et al

» Author Affiliations | Article Information

JAMA Surg. 2016;151(11):e162775. doi:10.1001/jamasurg.2016.2775

Results The final analysis of 309 330 fractures in 18 bones included 178 952 women (57.9%); mean (SD) age was 44.48 (13.68) years. The nonunion rate was 4.9%. Elevated nonunion risk was associated with severe fracture (eg, open fracture, multiple fractures), high body mass index, smoking, and alcoholism. Women experienced more fractures, but men were more prone to nonunion. The nonunion rate also varied with fracture location: scaphoid, tibia plus fibula, and femur were most likely to be nonunion. The ORs for nonunion fractures were significantly increased for risk factors, including number of fractures (OR, 2.65; 95% CI, 2.34-2.99), use of nonsteroidal anti-

FRACTURE HEALING



Indirect Healing

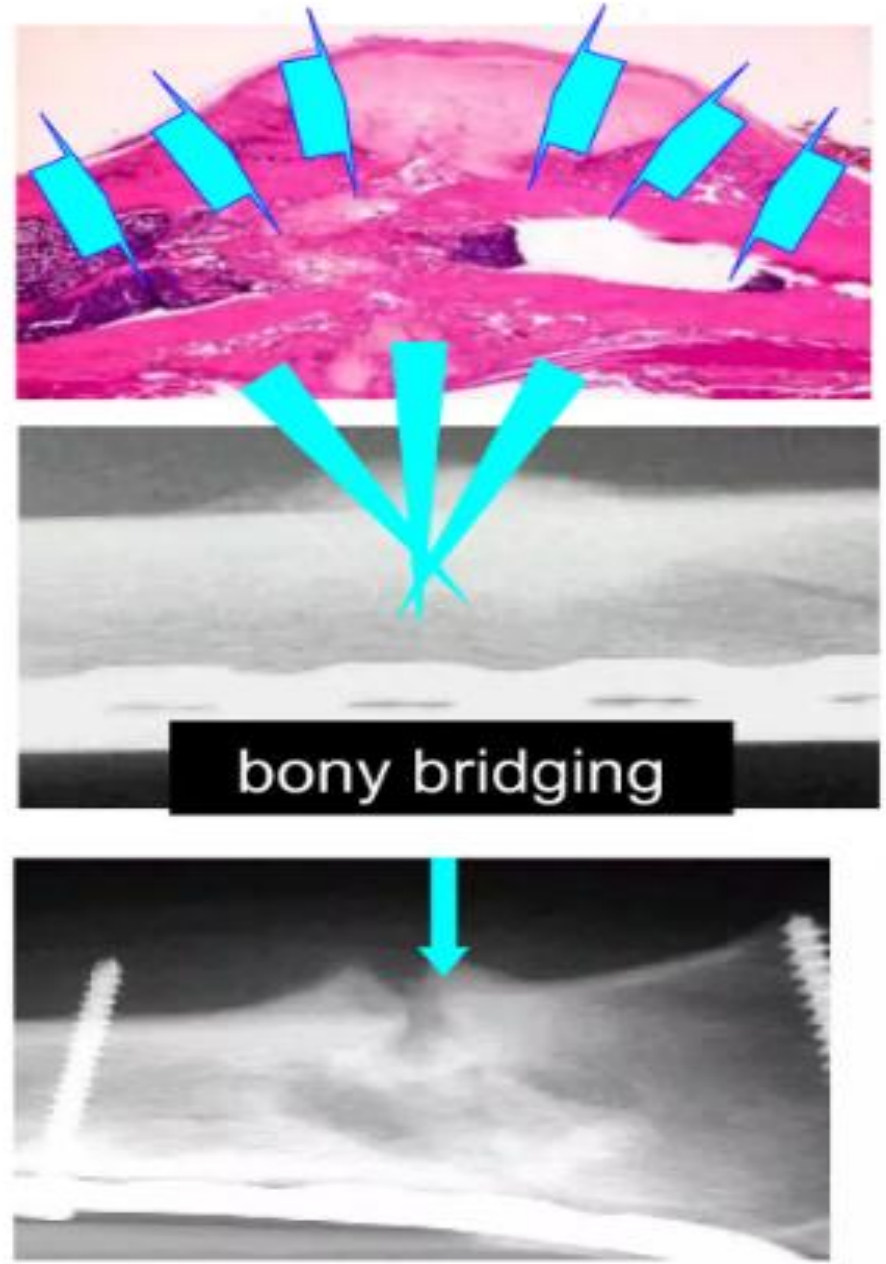
What does nature do with a broken bone?

It will heal by callus formation

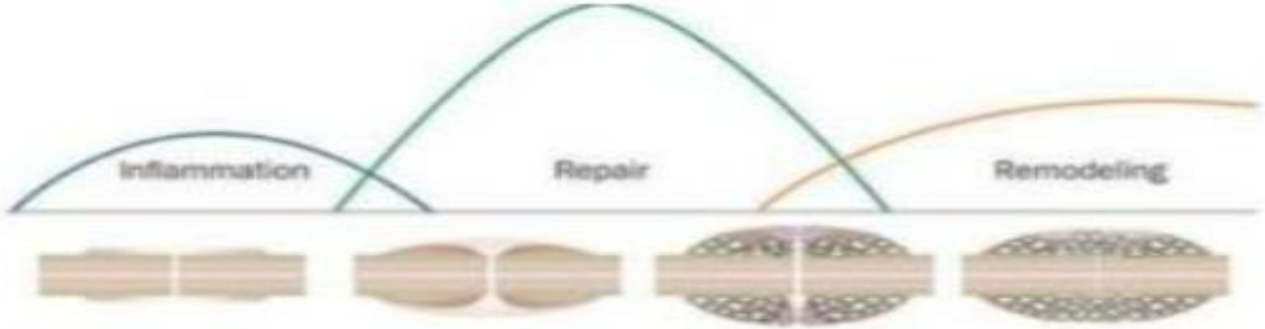
Fracture healing

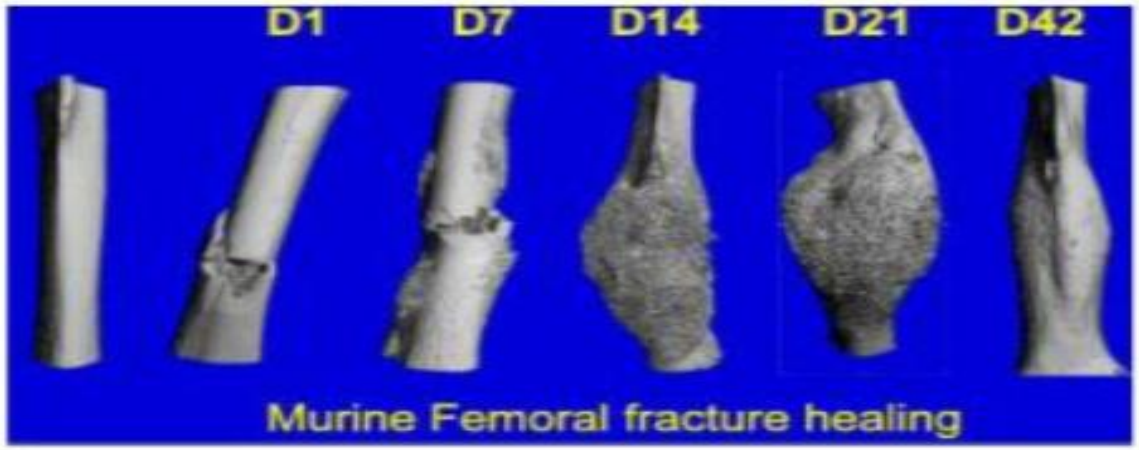
Stages of fracture healing

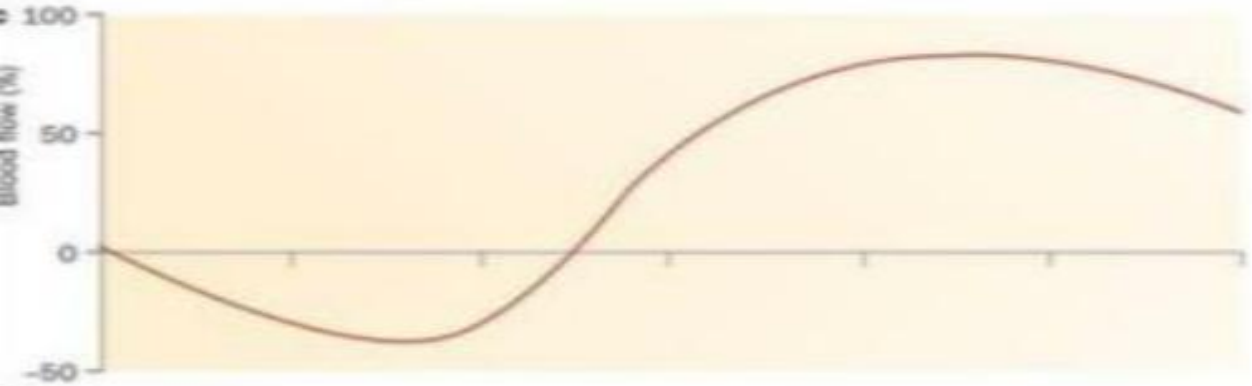
- Hematoma formation
- Inflammation and cellular proliferation
- Callus formation
- Consolidation
- Remodeling

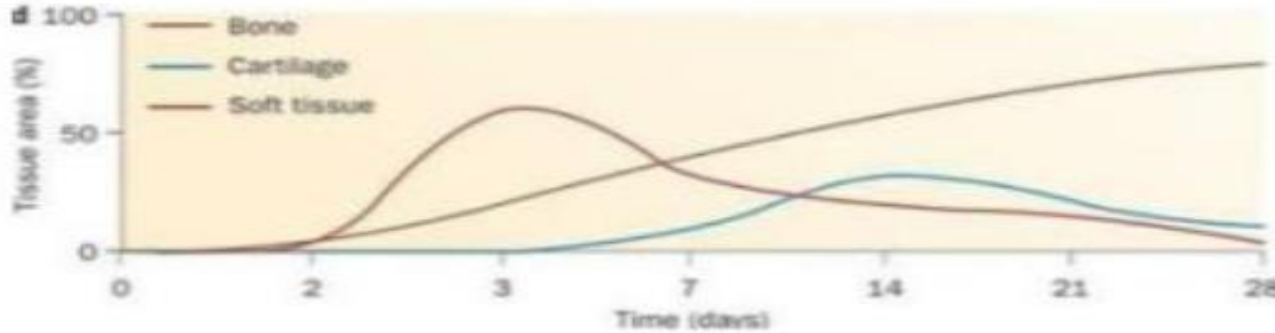


Time course of fracture healing









Caranoa RAD, Filvaroffb EH. Angiogenesis and bone repair. Drug Discovery Today. 2003;8(21): 980–989

Injury, Int. J. Care Injured (2007) 3854, S3-S6

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Fracture healing: The diamond concept

Peter V. Giannoudis[a,*], Thomas A. Einhorn[b], David Marsh[c]

[a]Academic Department of Trauma & Orthopaedics, Leeds Teaching Hospitals, University of Leeds, UK
[b]Department of Orthopaedic Surgery, Boston University Medical Center, Boston, USA
[c]Royal Orthopaedic Hospital, London, UK

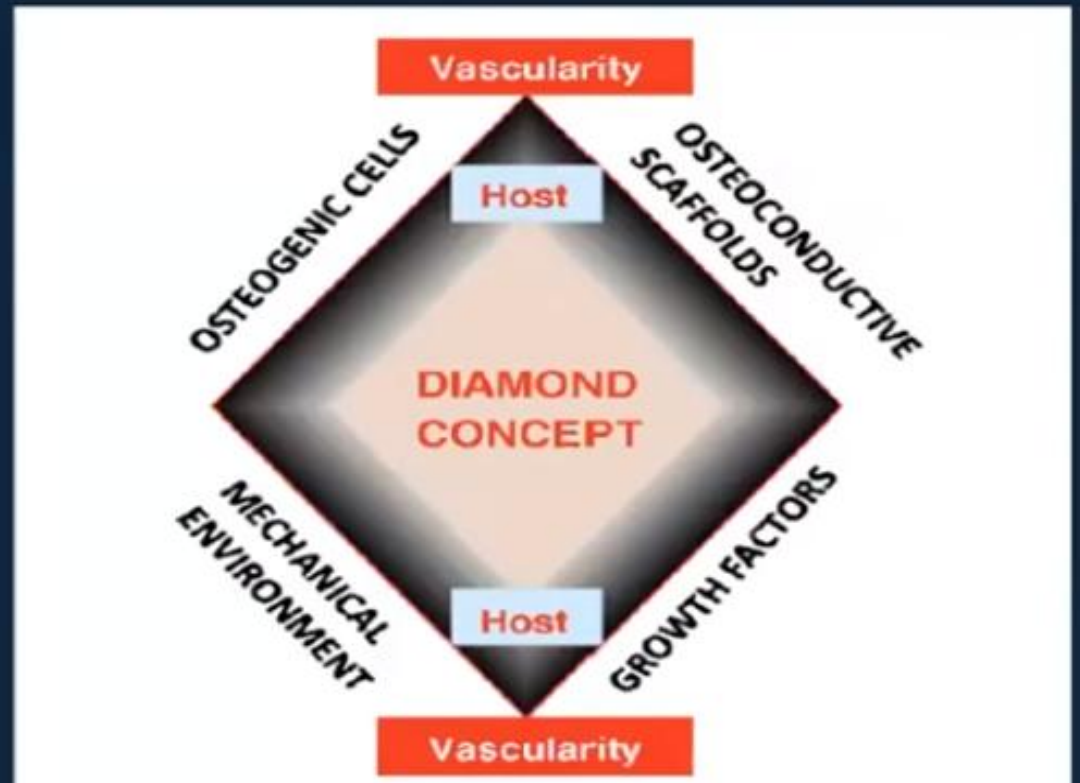


Fig. 1. The diamond concept.

Essential Requirements ?

Vascularity

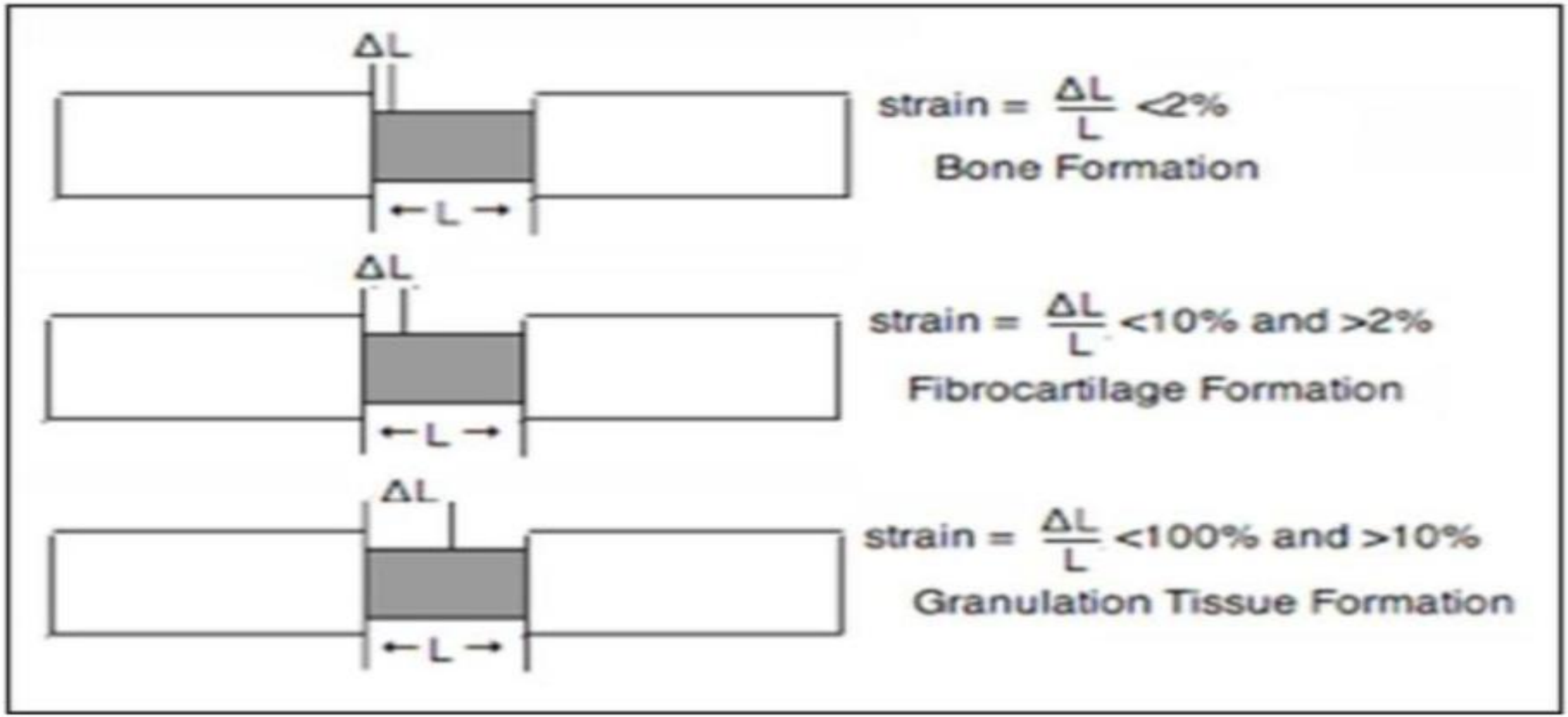
Stability

Progenitor Cells

Matrix

Growth Factor

Mechanism


ΔL
L
strain = ΔL/L <2%
Bone Formation
ΔL
L
strain = ΔL/L <10% and >2%
Fibrocartilage Formation
ΔL
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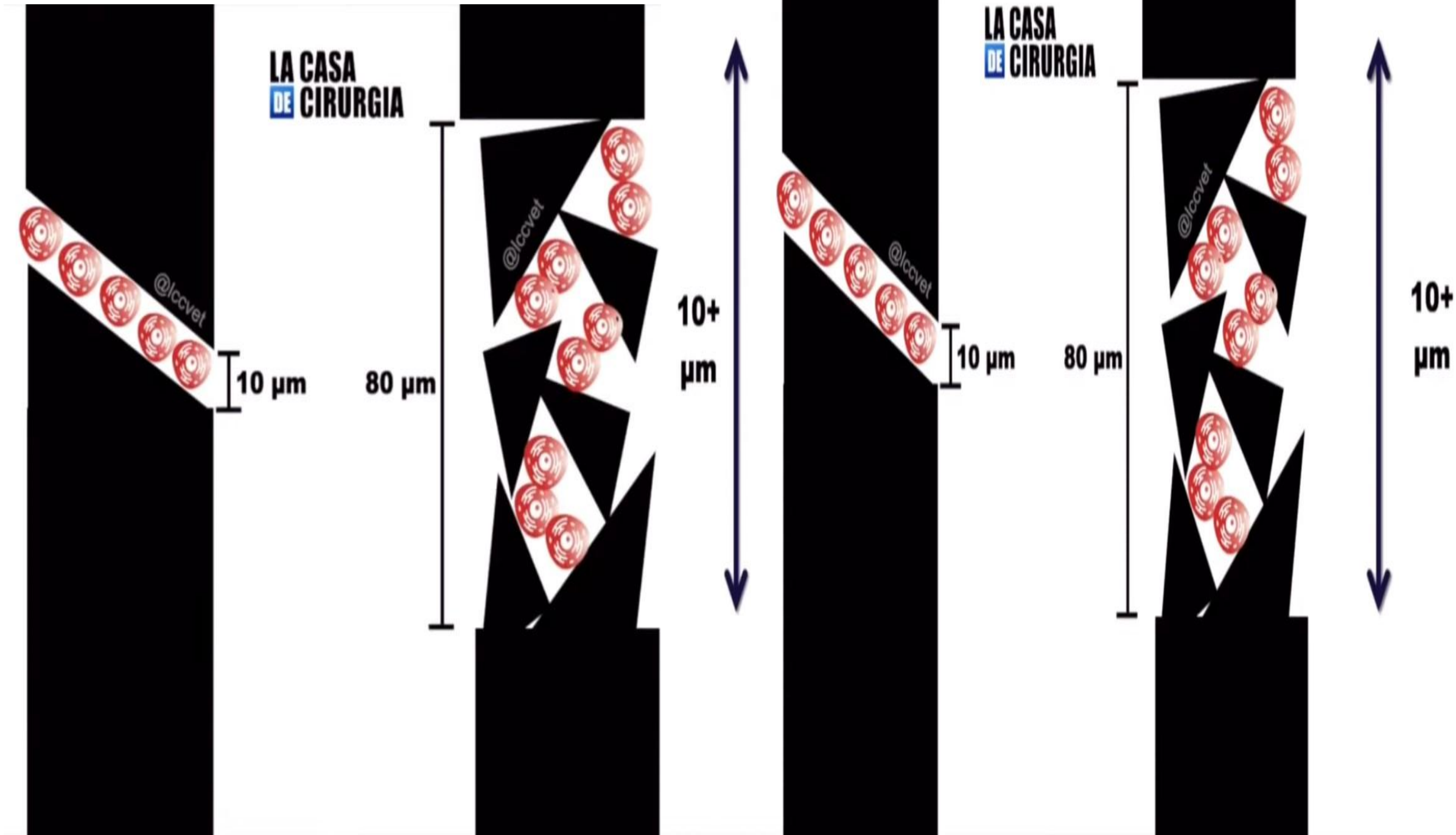
strain = ΔL/L <100% and >10%
Granulation Tissue Formation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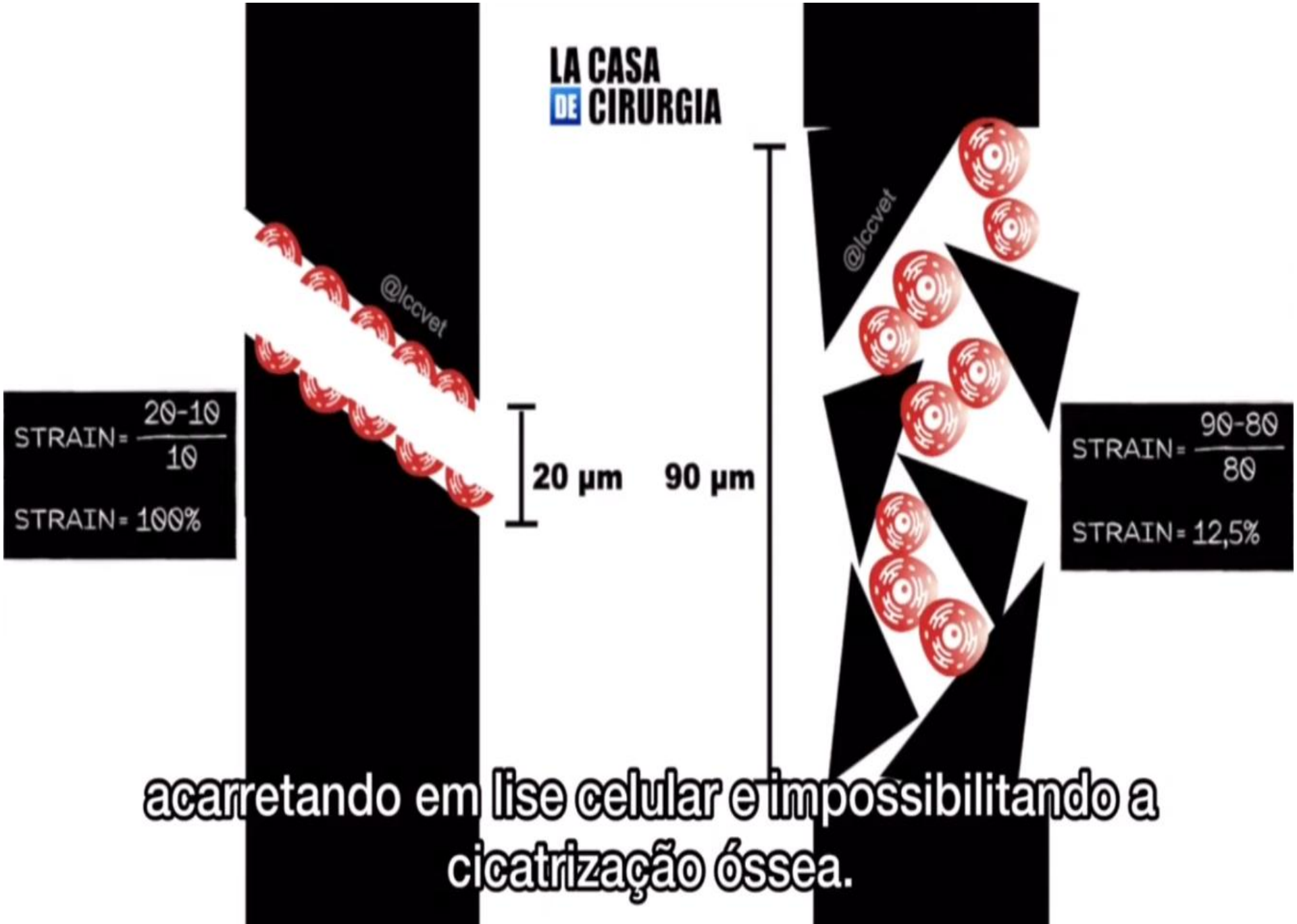

acarretando em lise celular e impossibilitando a cicatrização óssea.

NONUNION

Definition :

- ***Nonunion*** occurs when a fracture has failed to heal in the expected time (long bones 6 months , NOF 3 months) and is not likely to heal without new intervention.

  - **(FDA)** in the USA defines nonunion as follows: "…the decision that a non-union has been established should not be made until a minimum of nine months has elapsed since the injury, and the fracture site has shown no radiographical sign of healing progression, i.e., no change in the fracture callus, for the final three months "

- ***Delayed union*** occurs when a fracture has not completely healed in the time expected, **but still has the potential to heal without further intervention.**

- **Pseudoarthrosis** : subclassification of nonunion

because of excessive and chronic motion, an actual synovial pseudocapsule is formed, containing fluid much like an actual synovial joint

Pathophysiology, Etiology, and Risk Factors for Nonunion

Injury, Int. J. Care Injured (2007) 38S, S11–S18

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Risk factors contributing to fracture non-unions

G.M. Calori*, W. Albisetti, A. Agus, S. Iori, L. Tagliabue

Istituto Ortopedico G. Pini, Milan University, Milan, Italy

Risk factors contributing to non-union

General risk factors	Local risk factors
Gender	Fracture personality
Age	Type of fracture
Diet	Exposure
Diabetes	Infection
Osteoporosis	Multiple
Muscular mass	trauma/fracture
Smoking	
Alcohol NSAIDS	

In other words … the factors that can influence the rate and the likelihood of uncomplicated and timely fracture healing are :

- The characteristics of the original injury,
- the patient's ability (or inability) to generate a normal healing response to the particular injury,
- the mechanical and biologic environment created by the chosen treatment method,
- the presence or absence of associated infection

Fracture-Specific Factors Related to Nonunion

- The involved bone
- The specific location of the fracture within any given bone
- **The degree of soft tissue Injury**
- bone loss
- the degree of open fracture by virtue of its providing a source of bacterial contamination

AP radiograph (A) of an open tibial shaft fracture with associated periosteal stripping seen in the clinical photograph (B).

A

B

> J Bone Joint Surg Am. 2012 Aug 1;94(15):e1091-6. doi: 10.2106/JBJS.K.01344.

Variability in the definition and perceived causes of delayed unions and nonunions: a cross-sectional, multinational survey of orthopaedic surgeons

Mohit Bhandari [1], Katie Fong, Sheila Sprague, Dale Williams, Bradley Petrisor

Affiliations + expand

PMID: 22854998 DOI: 10.2106/JBJS.K.01344

Results: Three hundred and thirty-five surgeons completed the survey. The typical respondent was a North American, male orthopaedic surgeon or consultant over the age of thirty years who had completed trauma fellowship training, worked in an academic practice, supervised residents, and had more than six years of experience in treating orthopaedic injuries. Most surgeons endorsed a lack of standardization in definitions for delayed unions (73%) and nonunions (55%); almost all agreed that defining a delayed union and nonunion should be done on the basis of both radiographic and clinical criteria (88%). Most respondents believed that the degree of soft-tissue injury (approximately 93%), smoking history (approximately 82%), and vascular disease (approximately 76%) increased the risk of healing complications.

A 32-year-old male presents with an atrophic nonunion of his radius following open reduction internal fixation (ORIF) of a both bone forearm fracture treated 12 months ago. On radiographs an obvious fracture gap in the radius is appreciated. Which of the following is necessary for achievement of successful union in addition to revision ORIF with cancellous autograft?

1. Fracture gap less than 3 cm
2. Supportive soft tissue envelope
3. Healed ulna fracture
4. BMP-7
5. 4.5 mm plates

Host Factors Related to Nonunion :

- Smoking
- Vascular disease
- Diabetes
- exposure to certain medications (NSAIDs) ???
- the presence of osteoporosis , *Hypovitaminosis D*
- advanced age
- Malnutrition
- immunosuppression, including steroid use, Rheumatoid disease, and malignancy

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Foot Ankle Clin N Am
11 (2006) 805–824

FOOT AND
ANKLE CLINICS

Diabetic Fracture Healing

Ankur Gandhi, PhD, Frank Liporace, MD,
Vikrant Azad, MD, James Mattie,
Sheldon S. Lin, MD*

Department of Orthopaedics, University of Medicine & Dentistry-New Jersey Medical School, 185 South Orange Avenue, MSB G-574, Newark, NJ 07103, USA

Potential for patient with diabetes to develop a fracture

Progressive microvascular disease in diabetes can lead to decreased blood flow peripherally. Progressive decrease in perfusion to the lower extremities of patients has been shown to negatively affect bone mineral density. Those with marked decrease in

Patients with diabetic ankle fractures consistently are at greater risk of sustaining a complication during treatment than nondiabetics. Other medical comorbidities, especially Charcot neuroarthropathy and peripheral vascular disease, play distinct roles in increasing these complication rates. Many options for nonoperative and operative treatment exist, but respect for soft tissue management and attention to stable, rigid fixation with prolonged immobilization and prolonged restricted weight...

Peripheral neuropathy and hemoglobin A1c levels above 7% were significantly associated with bone-healing complications in the foot and ankle

Fracture, nonunion and postoperative infection risk in the smoking orthopaedic patient: a systematic review and meta-analysis

in EFORT Open Reviews

Authors: Maria Anna Smolle, Lukas Leitner, Nikolaus Böhler, Franz-Josef Seibert, Mathia View More +

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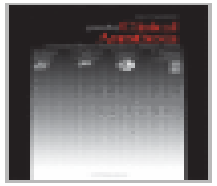
DOI: https://doi.org/10.1302/2058-5241.6.210058
Volume/Issue: Volume 6: Issue 11
Page Range: 1006–1019
Article Type: Review Article
Online Publication Date: 19 Nov 2021

Abstract

- This systematic review and meta-analysis aimed to analyse negative effects of smoking in orthopaedic and trauma patients.
- A PubMed search was carried out for studies published until July 2020 regarding effects of smoking on fracture risk, nonunion, infection after orthopaedic surgery, and persisting nonunion after scaphoid nonunion surgery. Random effects models calculated for outcome parameters, and relative risks (RR) with 95% confidence intervals are provided. No adjustments for covariates were made. Heterogeneity was assessed with Higgins' I2, publication bias with Harbord's p (Hp), sensitivity analysis performed on funnel plots and quality of studies was analysed using the Newcastle-Ottawa Scale.
- Of 3362 retrieved entries, 69 were included in the final analysis. Unadjusted RR for smokers to develop vertebral (six studies, seven entries; RR: 1.61; $p = 0.008$; $I2 = 89.4\%$), hip (11 studies, 15 entries; RR: 1.28; $p = 0.007$; $I2 = 84.1\%$), and other fractures (eight studies, 10 entries; RR: 1.75; $p = 0.019$; $I2 = 89.3\%$) was significantly higher. Postoperative infection risk was generally higher for smokers (21 studies; RR: 2.20; $p < 0.001$; $I2 = 58.9\%$), and remained upon subgroup analysis for elective spinal (two studies; RR: 4.38; $p < 0.001$; $I2 = 0.0\%$) and fracture surgery (19 studies; RR: 2.10; $p < 0.001$; $I2 = 58.5\%$). Nonunion risk after orthopaedic (eight studies; RR: 2.15; $p < 0.001$; $I2 = 35.9\%$) and fracture surgery (11 studies; RR: 1.85; $p < 0.001$; $I2 = 39.9\%$) was significantly higher for smokers, as was persisting nonunion risk after surgery for scaphoid nonunion (five studies; RR: 3.52; $p < 0.001$; $I2 = 0.0\%$). Sensitivity analysis for each model reduced heterogeneity whilst maintaining significance (all $I2 < 20.0\%$).
- Smoking has a deleterious impact on fracture incidence, and (subsequent) development of nonunions and postoperative infections.

Journal of Clinical Anesthesia
Volume 49, September 2018, Pages 92-100



The effect of nonsteroidal anti-inflammatory drugs on bone healing in humans: A qualitative, systematic review

Alain Borgeat [a], Christian Ofner [a], Andrea Saporito [b], Mazda Farshad [c], José Aguirre [a]

Published results of human trials did not show strong evidence that NDAIDs for pain therapy after fracture osteosynthesis or spinal fusion lead to an increased nonunion rate. Reviewed studies present such conflicting data, that no clinical recommendation can be made regarding the appropriate use of NSAIDs in this context. Considering laboratory data of animal, human tissue research and recommendation of clinical reviews, a short perioperative exposition to NSAIDs is most likely not deleterious. However, randomized, controlled studies are warranted to support or refute this hypothesis.

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ORIGINAL ARTICLE

Ketorolac Administered in the Recovery Room for Acute Pain Management Does Not Affect Healing Rates of Femoral and Tibial Fractures

Donohue, David MD*; Sanders, Drew MD†; Serrano-Riera, Rafa MD†,‡; Jordan, Charles MD§; Gaskins, Roger MD*; Sanders, Roy MD*,†; Sagi, H. Claude MD‖

Ketorolac administered **in the first 24 hours** after fracture repair for acute pain management does not seem to have a negative impact on time to healing or incidence of nonunion for femoral or tibial shaft fractures.

The issue is controversial and better to avoid NSAIDs in fx management

Treatment Factors Related to Nonunion :

- mechanical stability (excessive vs inappropriate)
- Improper technique
- Poorly fitting nails
- Rigid internal fixation with bone gaps
- Poor soft tissue handling and excessive stripping

Infection as a Factor Related to Development of Nonunion :

- The inflammatory process in response to infection may inhibit fracture healing by causing excessive remodeling and osteolysis
- Tissue necrosis may be accelerated by infection
- Loose nonvital bone fragments and bone pieces demarcated by osteoclastic activity are eventually transformed into sequestra
- Infection not only predisposes to nonunion, but also makes nonunion repair substantially more complex, often requiring multistaged treatment protocols

Contents lists available at ScienceDirect

Injury

journal homepage: www.elsevier.com/locate/injury

Full length article

Fracture-related infection: A consensus on definition from an international expert group

WJ. Metsemakers[a,s,*], M. Morgenstern[b], M.A. McNally[c], T.F. Moriarty[d], I. McFadyen[e], M. Scarborough[c], N.A. Athanasou[f], P.E. Ochsner[g], R. Kuehl[h], M. Raschke[i], O. Borens[j], Z. Xie[k], S. Velkes[l], S. Hungerer[m], S.L. Kates[n], C. Zalavras[o], P.V. Giannoudis[p,q], R.G. Richards[d], M.H.J. Verhofstad[r]

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[n] Department of Orthopaedic Surgery, Virginia Commonwealth University, USA
[o] Department of Orthopaedic Surgery, Keck School of Medicine, University of Southern California, Los Angeles, USA
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[q] NIHR Leeds Biomedical Research Unit, Chapel Allerton Hospital, Leeds, United Kingdom
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[s] KU Leuven - University of Leuven, Department Development and Regeneration, B-3000 Leuven, Belgium

Termonology:

the bone [20]. The term osteitis refers to a bone infection (starting with cortical bone involvement) most commonly caused by bacteria, that may lead to the complete destruction of the infected bone. In contrast, osteomyelitis refers to a primary infection of the bone marrow (myelitis) with subsequent involvement of the cortical bone and periosteum. The clinical and investigative findings of these diseases may be very similar and it can be

PJI :

In the definitions that describe infection after prosthetic joint replacement, [redacted]

The experts also agreed that a more comprehensive term was required, which encompassed infections with and without implants and included infection of all parts of the bone (cortical, medullary, epiphyseal). *Fracture-related infection* (FRI) was introduced as a more general term. The experts suggest that in the future, for reasons of uniformity, this term would be used in clinical publications on patients with infected fractures, in case no further detailed information (e.g. histopathology) would be available on the degree of bone involvement.

Location

A second challenge in developing a definition for FRI emerges with the location of the infection within the surgical site or wound, and includes descriptions such as '*superficial incisional infections*' [3]. The CDC published guidelines for surgical site infection (SSI), which distinguish between superficial incisional, deep incisional and organ/space infections [15–17]. Bonnevialle et al. state that the term 'superficial infection' is at best arbitrary [18], and poses particularly challenging problems in FRI. The depth of bacterial colonization can only be assessed by tissue samples taken under the subcutaneous tissue layer. This means that superficial swabs are no longer acceptable for diagnosis and every wound must be opened to take appropriate samples [18]. **In FRI, this would require the surgeon to open the surgical wound and expose both the implant and the fracture site in many cases (e.g. ankle fractures).** If the cultures are positive, this then defines a deep infection. Furthermore, in clinical studies regarding FRI, these terms (e.g. superficial and deep) are often used inaccurately or inappropriately, which makes comparison of literature difficult. In clinical practice, the presence of confirmatory or suggestive signs of an infection should be sufficient to alert clinicians of the need for treatment. The specifics of this treatment may be related to the nature of the infection (e.g. superficial cellulitis or deep infected non-union) but this is outside the remit of this definition proposal.

Unlike PJI, there can be numerous anatomical areas (i.e. humerus, tibia) involved in FRI. Although each area has its own features, this definition does not guide treatment principles. Subdividing a definition according to anatomical locations would make it unnecessarily complex. Also, the criteria used to diagnose an infection are not dependent on the anatomical location of the infection.

Classification

There are multiple classifications described in the literature that subdivide FRI into discrete groupings such as acute and chronic infections, or early, delayed and late onset infections [1,12–14]. One of the key questions for the experts was: should there be a single definition for FRI, or should a definition be subdivided into separate definitions for each classification (e.g. acute and chronic infection)? During the consensus meeting there was a *unanimous* decision that there should only be one single definition for FRI.

Two primary reasons were proposed for this decision: Firstly, a subdivision would make such a definition unnecessarily complex and difficult to use in daily practice. Secondly, the available classifications are time-related. These time windows are, to the best of our knowledge, not based on scientific evidence, which supports the view that they are poorly defined for FRI (e.g. time since injury, or time since onset of symptoms) and somewhat arbitrary (e.g. a 6 week transition from acute to chronic infection). All these concerns pose serious problems from a definition point of view [3]. Of course, the participants did agree that acute and chronic infections are different entities that may require different treatment strategies; however, it should not impact upon the way clinicians define FRI.

The experts agreed, that in a later phase, a similar process should be followed to achieve consensus on a classification of FRI to help develop treatment guidelines.

Confirmatory criteria for FRI

1. Fistula, sinus or wound breakdown (with communication to the bone or the implant).
2. Purulent drainage from the wound or presence of pus during surgery.
3. Phenotypically indistinguishable pathogens identified by culture from at least two separate deep tissue/implant (including sonication-fluid) specimens taken during an operative intervention. In case of tissue, multiple specimens ($\geq$3) should be taken, each with clean instruments (not superficial or sinus tract swabs). In cases of joint effusion, arising in a joint adjacent to a fractured bone, fluid samples obtained by sterile puncture may be included as a single sample.
4. Presence of microorganisms in deep tissue taken during an operative intervention, as confirmed by histopathological examination using specific staining techniques for bacteria or fungi.

Suggestive criteria for FRI

1. Clinical signs – any one of:
   - Pain (without weight bearing, increasing over time, new-onset)
   - Local redness
   - Local swelling
   - Increased local temperature
   - Fever (single oral temperature measurement of ≥38.3°C (101°F))
2. Radiological signs – any one of:
   - Bone lysis (at the fracture site, around the implant)
   - Implant loosening
   - Sequestration (occurring over time)
   - Failure of progression of bone healing (i.e. non-union)
   - Presence of periosteal bone formation (e.g. at localizations other than the fracture site or in case of a consolidated fracture)
3. A pathogenic organism identified by culture from a single deep tissue/implant (including sonication-fluid) specimen taken during an operative intervention. In case of tissue, multiple specimens (≥3) should be taken, each with clean instruments (not superficial or sinus tract swabs). In cases of joint effusion arising in a joint adjacent to a fractured bone, a fluid sample obtained by sterile puncture is permitted.
4. Elevated serum inflammatory markers: In musculoskeletal trauma, these should be interpreted with caution. They are included as suggestive signs in case of a secondary rise (after an initial decrease) or a consistent elevation over a period in time, and after exclusion of other infectious foci or inflammatory processes:
   - Erythrocyte sedimentation rate (ESR)
   - White blood cell count (WBC)

- C-reactive protein (CRP)

5. Persistent, increasing or new-onset wound drainage, beyond the first few days postoperatively, without solid alternative explanation.
6. New-onset of joint effusion in fracture patients. Surgeons should be aware that FRI can present as an adjacent septic arthritis in the following cases:
   - Implant material which penetrates the joint capsule (e.g. femoral nailing)
   - Intra-articular fractures

PJI :

Major criteria (at least one of the following)	Decision
Two positive cultures of the same organism	Infected
Sinus tract with evidence of communication to the joint or visualization of the prosthesis	

Preoperative Diagnosis		Minor Criteria	Score	Decision
	Serum	Elevated CRP *or* D-Dimer	2	≥6 Infected
		Elevated ESR	1	
	Synovial	Elevated Synovial *WBC or LE* (++)	3	2-5 Possibly Infected*
		Positive Alpha-defensin	3	
		Elevated Synovial PMN %	2	0-1 Not Infected
		Elevated Synovial CRP	1	

Postoperative Diagnosis	*Inconclusive pre-op score *or* dry tap	Score	Decision
	Preoperative score	-	≥6 Infected
	Positive Histology	3	4-5 Inconclusive**
	Positive Purulence	3	
	Positive Single Culture	2	≤3 Not Infected

* For patients with inconclusive minor criteria, operative criteria can also be used to fulfill definition for PJI for PJI.
**Consider further molecular diagnostics such as Next-generation sequencing.

AP radiograph of an infected nonunion of the femur after IM nailing.

Lateral radiograph and sagittal CT scan showing a sequestrum

A 54-year-old diabetic male underwent internal fixation for a humeral shaft nonunion 8 months ago, and denies any issues after surgery. However, over the past few weeks, he reports mild pain with activity. He denies any recent fevers or chills. Radiographs are shown in Figures A and B. What is the next most appropriate step in management?

1. CT scan of the humerus
2. Application of a functional fracture brace
3. Laboratory evaluation
4. Removal of hardware and intramedullary fixation
5. Revision plating with autograft

A 54-year-old diabetic male underwent internal fixation for a humeral shaft nonunion 8 months ago, and denies any issues after surgery. However, over the past few weeks, he reports mild pain with activity. He denies any recent fevers or chills. Radiographs are shown in Figures A and B. What is the next most appropriate step in management?

1 CT scan of the humerus

2 Application of a functional fracture brace

Laboratory evaluation

4 Removal of hardware and intramedullary fixation

5 Revision plating with autograft

Classification of Nonunion :

- **Nonunions may be classified based on the presence or absence of infection and the relative biologic activity of the fracture site.**
- **Septic nonunion** implies that there is an infectious process at the site while **aseptic nonunion** is the absence of infection
- Further classification of nonunion is an attempt at describing the **biologic occurrences or lack thereof at the fracture site**. **Atrophic, oligotrophic, and hypertrophic** nonunions
- **Radiographic analysis** is the most common method used to distinguish among these classification types

Classification of nonunion :

1. According to **location :**
   - Epiphyseal
   - metaphyseal
   - diaphyseal

2. Presence or absence of **infection :**
   septic vs Aseptic

3. **the biologic occurrences** :
   - Atrophic
   - Oligotrophic
   - Hypertrophic
   - Pseudoarthrosis

Atrophic Nonunion

- referred to as **avascular**, **nonviable**, or **avital** nonunion indicates poor healing response with little or no bone-forming cells active at the fracture site
- The blood supply to an atrophic nonunion is typically poor
- This is typically manifested **radiographically** by the **absence of any bone reaction**
- This lack of healing response may be **because of : the injury** (e.g., open fracture) or **subsequent surgical treatment** (e.g., surgical stripping of soft tissues about the fracture site) or because of **host issues** (e.g., diabetes or smoking)


A

Initial post op xrays

Xrays after 3 months post op

Hypertrophic Nonunion:

- referred to as **hypervascular**, **viable**, or **vital** nonunion. Associated is an adequate healing response with satisfactory vascularity.
- These fractures **lack adequate stability** to progress to union.
- The viable healing fibrocartilage cannot mineralize because of unfavorable mechanical factors at the fracture site.
- This is **manifested radiographically** by **callus formation**, usually abundant, with an interceding area of fibrocartilage-lacking mineral, and so **appearing dark on standard radiographs** (Elephant foot)


a
b

Oligotrophic Nonunion :

- represent a condition somewhere between atrophic and hypertrophic nonunions
- **They are viable**, but usually manifest **minimal radiographic healing** reaction (callus)
- **inadequate approximation of the fracture surfaces**
- A **bone scan** may be necessary to distinguish this type of nonunion from a frankly atrophic one. (**oligotrophic - increased uptake** where the **atrophic - relative cold**)

An oligotrophic femoral shaft nonunion after initial IM nailing (A) treated with exchange nailing (B) healed uneventfully (C), probably as the result of bone graft generated by reaming and improved stability.

A, B C

Pseudoarthrosis :

- subclassification of nonunion
- has **properties of hypertrophic nonunion**, but because of excessive and chronic motion, an actual synovial pseudocapsule is formed, containing fluid much like an actual synovial joint
- **The medullary ends are usually sealed** and an **interceding cold cleft is noted on bone scan**
- Management of these nonunions usually requires **debridement of the pseudoarthrosi**s, **opening of the medullary canal**, and **enhancement of stability**, typically with **compression** at the nonunion site.

Pseudoarthrosis in 20 years pt , after shotgun injury and nonoperative treatment.

Congenital pseudarthrosis of the tibia(6.6 yr old pt) . And At 12.8 years old, 6.2 years after **VFG** (B)

Evaluation and Diagnosis of Nonunion :

- The Most critical step
- The goal :
  - to discover the **etiology** of the nonunion
  - To form a **plan** for healing the nonunion

- Use a work sheet

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Patient History :

- Date and mechanism of injury of the initial fracture
- Preinjury medical problems, disabilities, or associated injuries
- Pain and function limitations
- Details of each prior surgical procedures such as nail dynamization.
- Prior treating surgeons & review all medical records (open wounds, contamination , Cx reports , crush injuries , periosteal stripping , devitalized bone fragments , etc)

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- IV and oral Abx use
- Problems with wound and episodes of soft tissue breakdown
- Perioperative complication (venous thrombosis , nerve injuries , etc)
- Adjuvant nonsurgical therapies

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- NSAIDs use and its use discontinued
- Cigarette smoking

- From practical standpoint, however it is **unrealistic** to delay treatment of symptomatic nonunion until the PT stops smoking

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Physical exam:

- The general health and nutritional status
- The skin and soft tissue
- Active drainage, sinus formation, deformity
- Manually stressed to evaluate motion and pain
- Neurovascular examination
- Active and passive ROM of adjacent joints
- Anterior and posterior iliac crests

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Worksheet for patients with nonunions.

GENERAL INFORMATION

Patient Name: _____ Age: _____ Gender: _____

Referring Physician: _____ Height: _____ Weight: _____

Injury (description): _____

Date of Injury: _____

Mechanism of Injury: _____ Pain (0 to 10 VAS): _____

Occupation: _____ Was Injury Work Related?: Y N

PAST HISTORY

Initial Fracture Treatment (Date): _____

Total # of Surgeries for Nonunion: _____

Surgery #1 (Date): _____

Surgery #2 (Date): _____

Surgery #3 (Date): _____

Surgery #4 (Date): _____

Surgery #5 (Date): _____

Surgery #6 (Date): _____

(Use backside of this sheet for other prior surgeries)

Use of Electromagnetic or Ultrasound Stimulation? _____

Cigarette Smoking # of packs per day _____ # of years smoking _____

History of Infection? (include culture results) _____

History of Soft Tissue Problems? _____

Medical Conditions: _____

Medications: _____

NSAID Use: _____

Narcotic Use: _____

Allergies: _____

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PHYSICAL EXAMINATION

General: _____

Extremity:

Nonunion: _____ Stiff _____ Lax

Adjacent Joints (ROM, compensatory deformities): _____

Soft Tissues (defects, drainage): _____

Neurovascular Exam: _____

RADIOLOGIC EXAMINATION

Comments _____

OTHER PERTINENT INFORMATION _____

_____

_____

NONUNION TYPE

_____ Hypertrophic

_____ Oligotrophic

_____ Atrophic

_____ Infected

_____ Synovial Pseudarthrosis

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Radiographic Assessment of Nonunion

- **Plain radiographs :**
- **Original Fx films :**
  - Initial boney injury
  - The progression and the lack of progress
  - Status of orthopaedic hardware
- **Subsequent radiographs** :
  - Evolution of deformits
  - Missing or removed boney fragment
  - Added bone grafts
  - Implanted bone stimulators

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- Current Radiographs :
  - AP _Lateral and two Oblique views
  - Small cassette films
  - Bilateral Ap and Lateral 51-in
  - Flexion/Extension lateral radiographs

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A patient with an open distal humeral shaft fracture (A) was treated with irrigation and debridement and plate fixation (B). Despite having a nonunion at 6 months, she was functioning well and without pain because of the stability provided by the plate. **C:** An acute increase in pain resulted from failure of the plate. **D:** The fracture then healed in slight varus without further surgery.

A distal humerus fracture treated with rigid fixation (A) yielded fracture healing without callus (B).

The radiographic union scale in tibial (RUST) fractures

Reliability of the outcome measure at an independent centre

J. M. Leow, Medical Student,[✉1] N. D. Clement, MD, PhD, Speciality Trainee,[2] T. Tawonsawatruk, Medical Student,[3] C. J. Simpson, MRCS, PhD, Speciality Trainee,[4] and A. H. R. W. Simpson, MA (Cantab), DM (Oxon), FRCS (England & Edinburgh), George Harrison Law Professor of Orthopaedic Surgery[5]

TABLE I RUST and mRUST Scoring Criteria

	Radiographic Criteria		
	Callus	Fracture Line	Score*
RUST	Absent	Visible	1
	Present	Visible	2
	Present	Invisible	3
mRUST	Absent	Visible	1
	Present	Visible	2
	Bridging	Visible	3
	Remodeled	Invisible	4

*A score is given to each of the visible cortices in 2 orthogonal radiographs (anteroposterior and lateral). The final score is the sum of the 4 cortex scores.

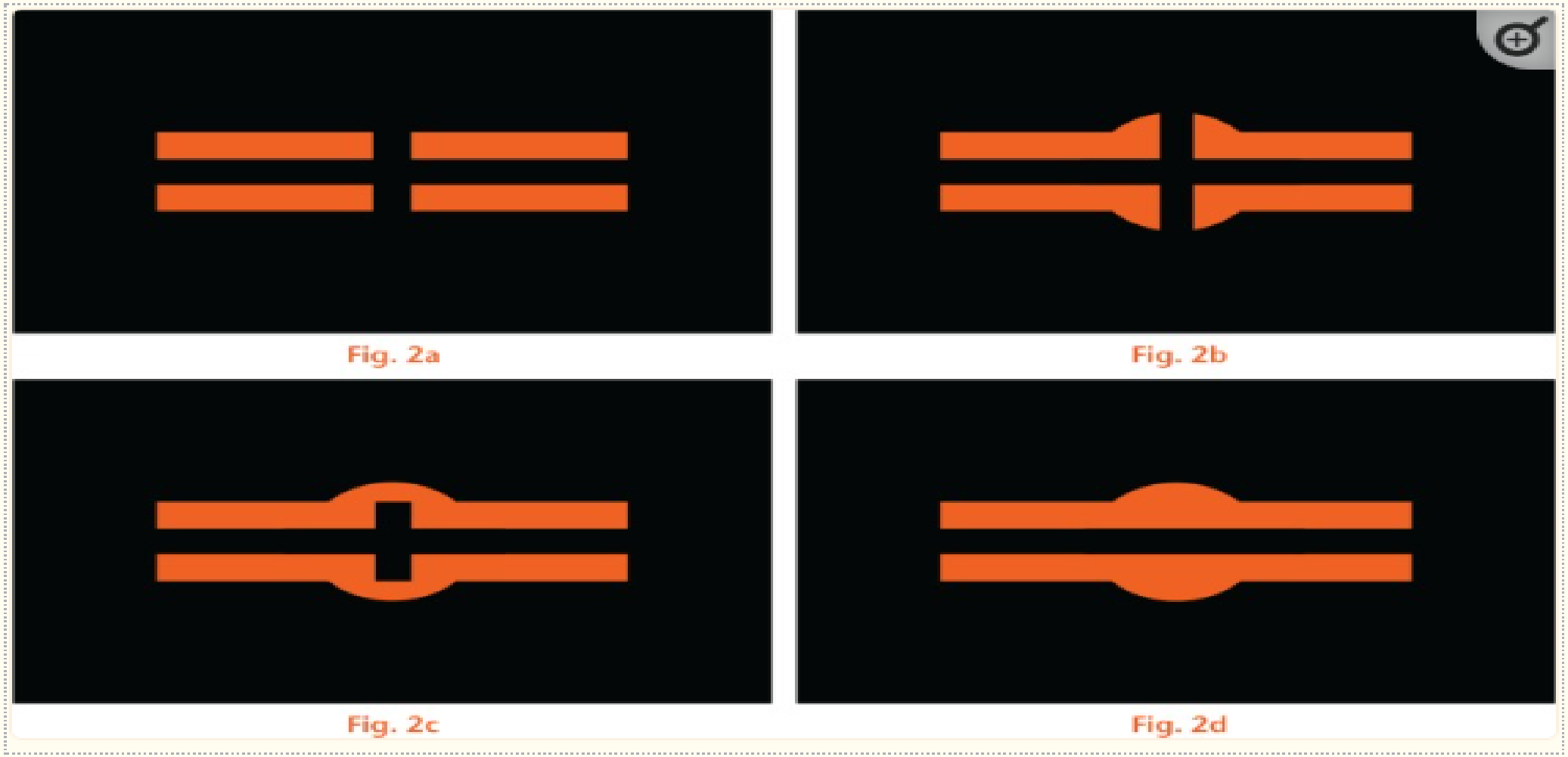

Fig. 2a

Fig. 2b

Fig. 2c

Fig. 2d

Diagrams showing a) a fracture with a fracture line and no callus formation; this would be assigned a radiographic union scale in tibial (RUST) fracture score of 1; b) a fracture with callus formation and a fracture line; this is scored as 2; c) a fracture with bridging callus, but the fracture line is still visible across both cortices; this is scored as 3 and d) complete bridging of the callus with no evidence of fracture line and is scored as 3.

8 Weeks 14 Weeks 20 Weeks

mRUST Scoring System (per Litrenta et al. 2015)

Score assigned to each cortex:

Criteria	Point(s)
Visible Fracture Line, No Callus	1
Visible Fracture Line, Visible Callus	2
Visible Fracture Line, Bridging Callus	3
No Fracture Line, Remodeled	4

→

2 Cortices Scored from Lateral Radiograph
+
2 Cortices Scored from Anterior-Posterior Radiograph

→

Total Score

Minimum: 4

Maximum: 16

Computer Tomography

- Estimate percentage of the cross-sectional area that shows bridging bone
  - < 5% in Nonunion
  - >25% in healed or healing Fx Nonunion
- Intraarticular Nonunions
  - Articular step-off
  - Joint incongruence
- Rotational deformities
- **CT scan highly sensitive (100%) but Lack of specificity (62%) in the diagnosis of nonunion.**

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AP (A) and lateral (B) radiographs 6 months after repair of a distal humeral nonunion show equivocal healing.

C: Coronal CT demonstrates a lucent line consistent with nonunion prompting revision nonunion repair where solid healing, rather than nonunion, was encountered.

Further scrutiny of the CT reveals healing of the posterior cortices of the medial (D) and lateral (E) columns

Nuclear Imaging

- Bone vascularity at the nonunion site
- The presence of synovial Pseudoarthrosis (cold cleft between two intense areas of uptake
- Infection
  - Increased blood flow and blood pool as demonstrated during the first and second phases of a three-phase bone scan are consistent with the inflammatory reaction seen with infection, but are not pathognomonic for infection.
  - Combined use of a 99mTc and a 67Ga scan has produced inconsistent results for accurately detecting infection at the site of nonunion

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- Technitium-99m – prophosphate (“bone scan”)
- Radiolabled White Blood Cells Scan (such as with Indium-111 or Technitium-99m –HMPAO { HexaMethylPropylene Amine Oxide})
- Gallium scan is useful in the evaluation of chronic bone infection

- **Newer technologies** such as **single-photon emission computed tomography (SPECT)** have been investigated for use in differentiating infected from noninfected and vital from nonvital nonunions.
  - high specificity but low sensitivity to confirm nonviability at a nonunion site

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Laboratory Studies for the Diagnosis of Nonunion

- **Markers of bone metabolism are natural targets for such investigation but have not yet been proven to be clinically reliable**
- General health :
  - Electrolytes
  - CBC
  - Albumin level , transferrin level
- Infection :
  - ESR , CRP
  - Aspiration and biopsy (cell count and gram stain , Cx for aerobic, anaerobic , fungal , acid-fast bacillus organisms. All Abx should be discontinued at least for 2 weeks prior to aspiration)

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Prediction of Nonunion

- Squared-Error Skill Score (SESS), at 6 and 12 weeks after treatment of 39 femur and tibia fractures .
- The Nonunion Risk Determination (NURD) score was used at the time of definitive fixation

- These investigations suggest that waiting an arbitrary length of time, such as at least 6 months

NURD 2.0: Prediction of tibial nonunion after intramedullary nail fixation at any time within 3 months after injury

Robert V. O'Toole • Josef Jolissaint • Kevin O'Halloran • ... Keir Ross • Justin Fowler • Renan C. Castillo • Show all authors

Published: December 26, 2020 • DOI: https://doi.org/10.1016/j.injury.2020.12.024 •

- retrospective review at a Level I academic trauma center
- The study cohort consisted of patients with tibial shaft fractures treated with nail insertion from 2007 through 2014
- 382 patients at time 0, 323 at 6 weeks, and 240 at 12 weeks
- The Nonunion Risk Determination (NURD) score was used at the time of definitive fixation and assigned:

  5 points for flaps, **4 points** for compartment syndrome,
  3 points for chronic conditions, **2 points** for open fractures,
  1 point for : male gender, American Society of Anesthesiologists Physical Status and percent cortical contact, spiral fractures and for low-energy injuries
- NURD score of **0 to 5** had a 2% chance of nonunion; **6 to 8** has 22% ; **9 to 11** has 42%; and **more than 12** has 61%

Systematic review | Open Access | Published: 03 September 2020

Prevalence and influencing factors of nonunion in patients with tibial fracture: systematic review and meta-analysis

Ruifeng Tian, Fang Zheng, Wei Zhao, Yuhui Zhang, Jinping Yuan, Bowen Zhang & Liangman Li

Journal of Orthopaedic Surgery and Research **15**, Article number: 377 (2020) | Cite this article

Abstract

Objective

The aim of this study is to assess the prevalence of nonunion in patients with tibia fracture and the association between influencing factors and tibia fracture nonunion.

Method

A database searches of PubMed, the Cochrane Library, EMBASE, China National Knowledge Infrastructure (CNKI), Weipu database, and Wanfang database from inception until June 2019 was conducted. The pooled prevalence, odds ratio (OR), and 95% confidence intervals (CI) were calculated with Stata software.

- In this study, 111 studies, involving 41,429 subjects .
- The prevalence of nonunion in patients with tibia fracture was 0.068 and ***15 potential factors*** were associated with the prevalence including :

> 60 years old,
tobacco smoker,
diabetes,
opioids user,
high-energy fracture,
open fracture,
open reduction,
Infection
male gender ,
body mass index > 40
(NSAIDs) user,
fracture of middle and distal tibia
Müller AO Classification of Fractures C
Gustilo-Anderson grade IIIB or IIIC
fixation model

- **Closed reduction and minimally invasive percutaneous plate osteosynthesis (MIPPO) have the low risks of nonunion for the treatment of tibial fractures.**

NONUNION TREATMENT

TREATMENT :

Objectives:

- Treatment is directed at healing the fracture
- Returning the extremity and the patient to the fullest function possible

The treatment plan is broken into stages with the following priorities:

1. Heal the fracture
2. Eradicate the infection
3. Correct deformities
4. Maximize the joint motion and the muscle strength

Strategies

- Based on accurate classification of the nonunion
- Classification is based on the nonunion type and treatment modifiers

Nonunion Type

1. Hypertrophic n0nunion
2. Oligotrophic nonunion
3. Atrophic nonunion
4. Infected nonunion
5. Synovial pseudarthrosis

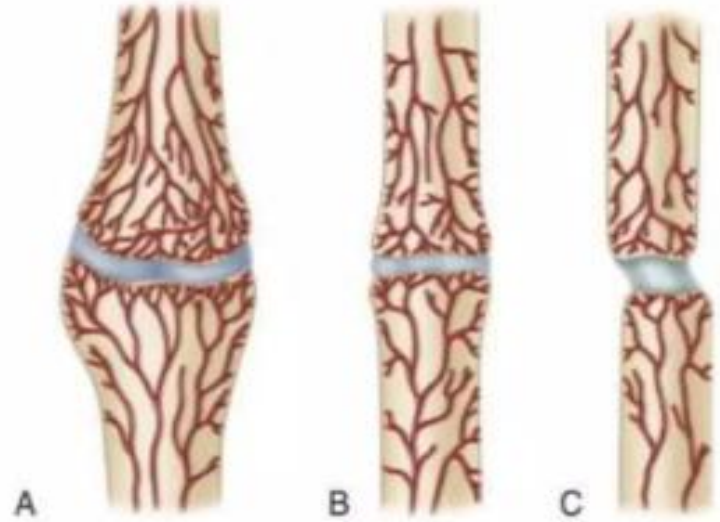
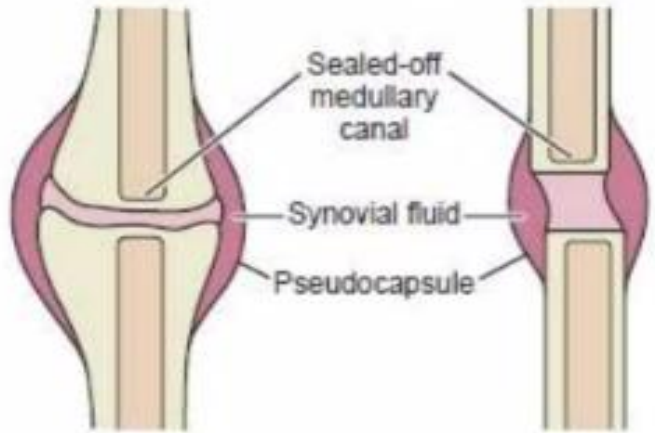


FIGURE 59-3 Types of nonunions. A, Hypertrophic. B, Oligotrophic. C, Atrophic.

Synovial Pseudarthrosis



1. HYPERTROPHIC NONUNIONS

- Viable, possess an adequate blood supply
- display abundant callus formation
- Provide mechanical stability – via compression plate or Intramedullary nail or external fixation
- Require no bone grafting

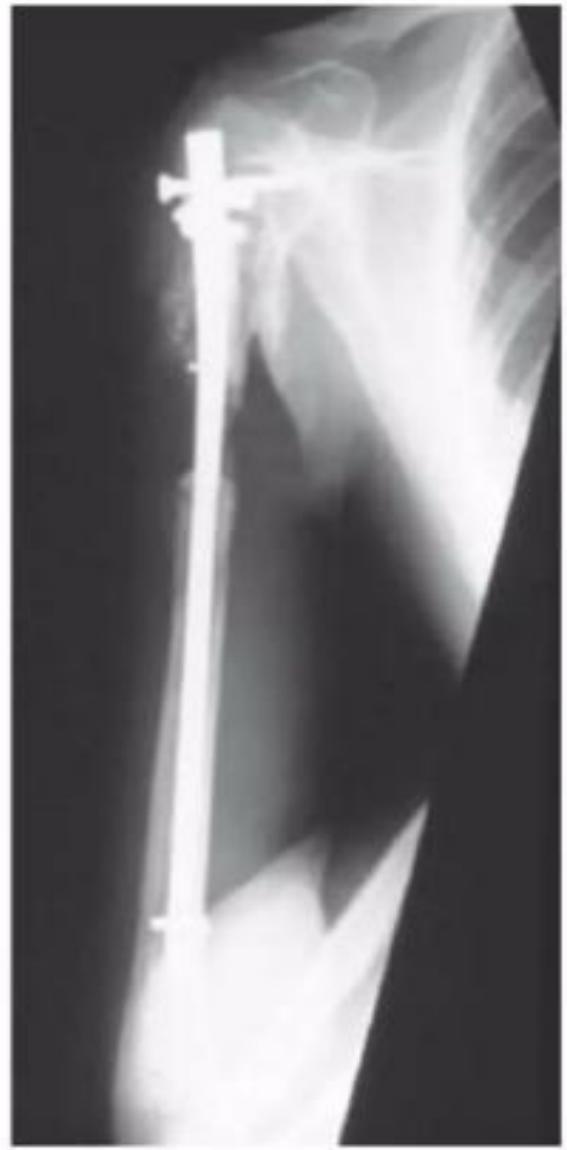
FIGURE 59-4 A and B, Hypertrophic humeral nonunion.

2. OLIGOTROPHIC NONUNIONS

- Viable and possess an adequate blood supply
- display little or no callus formation
- result of inadequate reduction with little or no contact at the bony surfaces
- reduction of the bony fragments to improve bone contact; bone grafting to stimulate the local biology; or a combination of both
- Bone grafting - poor surface characteristics and no callus formation

3. ATROPHIC NONUNIONS

- Nonviable, blood supply is poor – incapable of purposeful biological activity
- both biological and mechanical techniques
- Biological stimulation - autogenous cancellous graft
- Mechanical stability - internal or external fixation



4. INFECTED NONUNIONS

- Dual challenge: bone infection and ununited fracture
- the most difficult nonunion type to treat

- Goals - to obtain solid bony union, eradicate the infection, and maximize function of the extremity and the patient

- Counseling to Patient and the family
  - ✓ Course of treatment is difficult to predict
  - ✓ Possibility of persistent infection, nonunion, future amputation

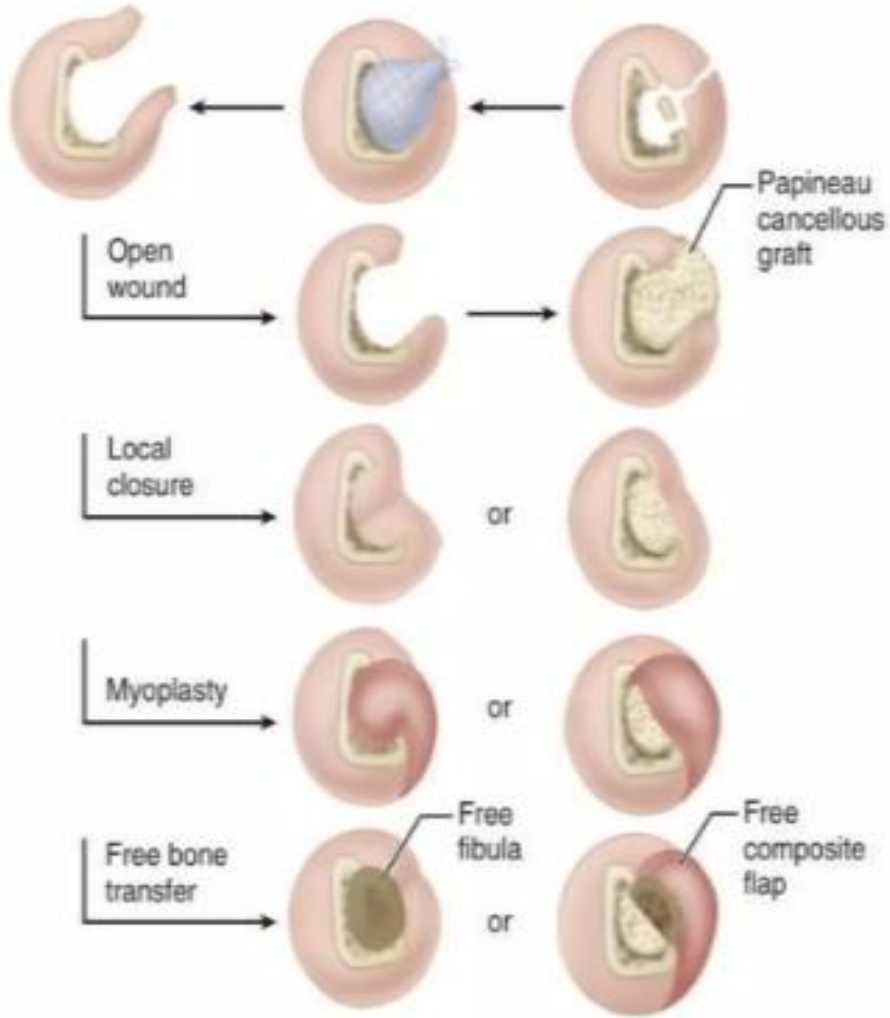
- Nature of infection - draining, nondraining-active, nondraining-quiescent
- Involves both biological and mechanical approach

4. INFECTED NONUNIONS

ACTIVE PURULENT DRAINAGE

- When purulent drainage is ongoing, the nonunion takes longer and is more difficult to heal
- Requires serial debridement
- The first debridement should include obtaining deep cultures, including specimens of soft tissues and bone
- No perioperative antibiotics should be given at least 2 weeks prior to obtaining deep intraoperative cultures

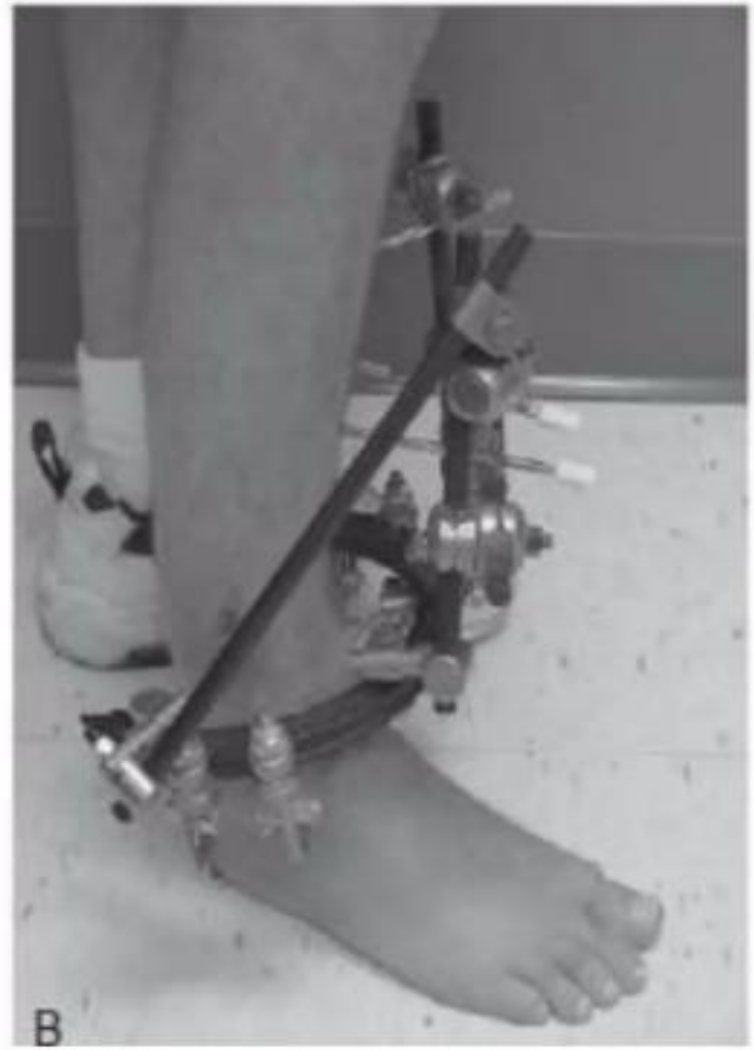
- Dead space follows debridement
- Initially, antibiotic-impregnated polymethylmethacrylate (PMMA) beads are inserted
- Bead exchange - at each serial debridement
- Rotational vascularized muscle pedicle flap (e.g., gastrocnemius or soleus) or a microvascularized free flap (e.g., latissimus dorsi, rectus)
- Papineau technique - open wound care with moist dressings
- Systemic antibiotic therapy according to culture result



4. INFECTED NONUNIONS

ACTIVE NONDRAINING

- Present with swelling, tenderness, and local erythema, fever
- Treatment principles - similar to actively draining infected nonunions
- Typically require incision and drainage of an abscess
- Followed by primary closure/closed suction-irrigation drainage system until the infection becomes quiescent



4. INFECTED NONUNIONS

QUIESCENT

- Occur in patients with
  - ✓ a history of infection but without drainage or symptoms for 3 or more months or
  - ✓ without a history of infection but with a positive indium or gallium scan

- Treated like atrophic nonunions

5. SYNOVIAL PSEUDARTHROSIS

- Fluid bounded by sealed medullary canals and a fixed synovium-like pseudocapsule
- Treatment - both biological and mechanical
- The synovium and pseudarthrosis tissue are excised
- Medullary canals of the proximal and distal fragments are drilled and reamed

Which of the following nonunions is appropriately treated with exchange reamed nailing without bone graft augmentation?

1. Infected tibial shaft nonunion 6 months status post intramedullary nail fixation
2. Oligotrophic humeral shaft nonunion 7 months status post non-operative management
3. Hypertrophic tibial shaft nonunion 7 months status post intramedullary nail fixation
4. Comminuted open tibial shaft nonunion with segmental bone loss 8 months status post intramedullary nail fixation
5. Supracondylar femoral shaft nonunion 6 months status post intramedullary nail fixation with 4 distal locking screws

Which of the following nonunions is appropriately treated with exchange reamed nailing without bone graft augmentation?

1. Infected tibial shaft nonunion 6 months status post intramedullary nail fixation
2. Oligotrophic humeral shaft nonunion 7 months status post non-operative management
3. Hypertrophic tibial shaft nonunion 7 months status post intramedullary nail fixation
4. Comminuted open tibial shaft nonunion with segmental bone loss 8 months status post intramedullary nail fixation
5. Supracondylar femoral shaft nonunion 6 months status post intramedullary nail fixation with 4 distal locking screws

Case discu

The nonunion as seen in Figure A will most likely unite by what intervention?

1. Increased mechanical stability
2. Decreased mechanical stability
3. Increased biology at the fracture site
4. Decreased biology at the fracture site
5. Antibiotics and resection of pseudoarthrosis

The nonunion as seen in Figure A will most likely unite by what intervention?

1. Increased mechanical stability
2. Decreased mechanical stability
3. Increased biology at the fracture site
4. Decreased biology at the fracture site
5. Antibiotics and resection of pseudoarthrosis

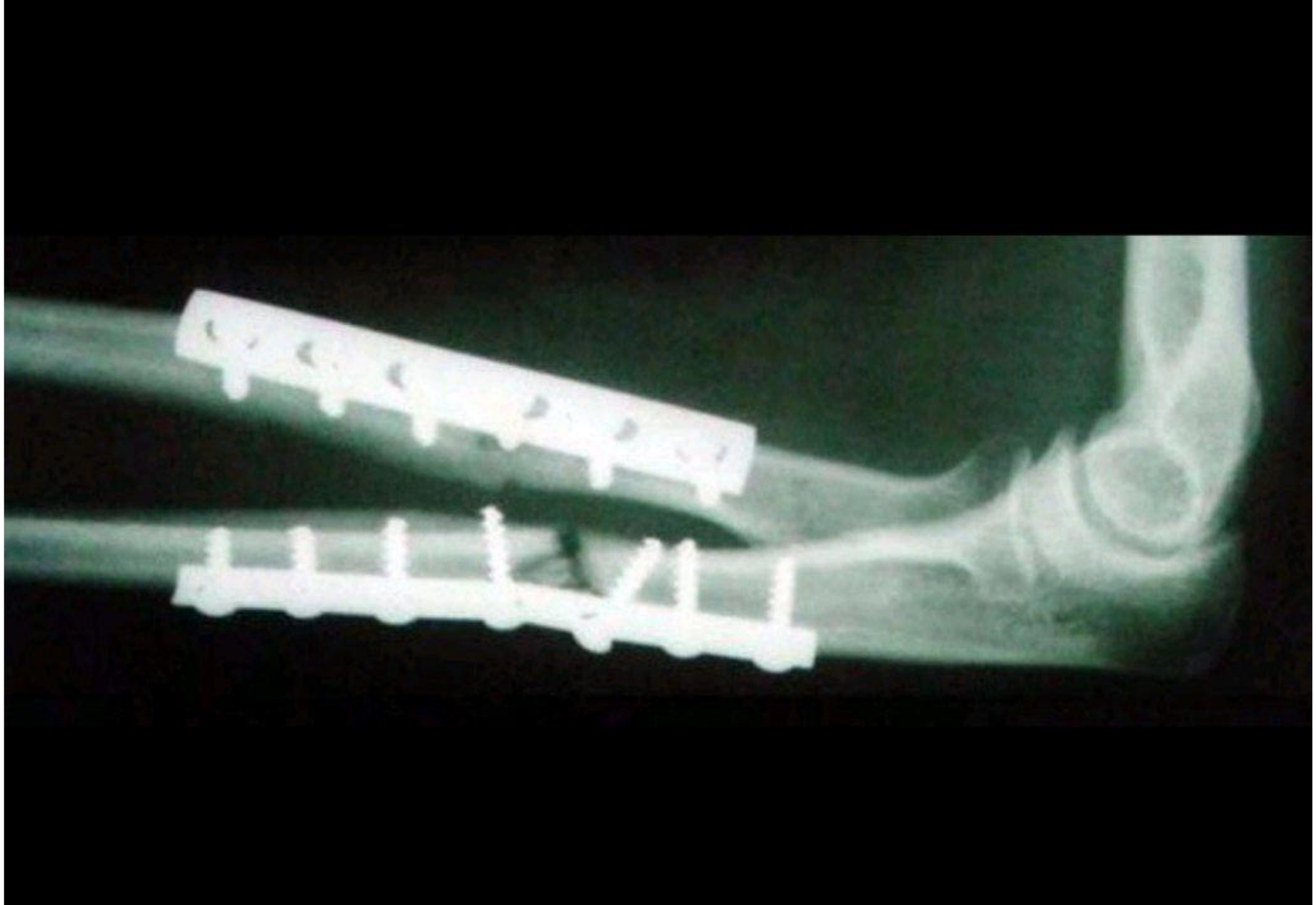


Figure A is the radiograph of a 52-year-old male who underwent open reduction and internal fixation (ORIF) of a both bone forearm fracture six months prior. He complains of persistent pain at the ulna fracture site. His C-reactive protein and erythrocyte sedimentation rate are within normal limits. What is the most appropriate definitive treatment for this patient?

1. Observation with repeat radiographs in 6 months
2. Short arm cast immobilization
3. Removal of hardware with intramedullary nail placement
4. Revision ORIF without graft
5. Revision ORIF with autograft

Figure A is the radiograph of a 52-year-old male who underwent open reduction and internal fixation (ORIF) of a both bone forearm fracture six months prior. He complains of persistent pain at the ulna fracture site. His C-reactive protein and erythrocyte sedimentation rate are within normal limits. What is the most appropriate definitive treatment for this patient?

1. Observation with repeat radiographs in 6 months
2. Short arm cast immobilization
3. Removal of hardware with intramedullary nail placement
4. Revision ORIF without graft
5. Revision ORIF with autograft

Thank you

TREATMENT MODIFIERS :

- Anatomical location – epiphyseal , metaphyseal , diaphyseal
- Segmental bone defects
- Prior failed treatment
- Deformities – length, alignment, rotation and translation
- Surface characteristics
- Pain and Function
- Osteopenia
- Mobility of the nonunion limb – stiff , lax
- Status of Hardware
- Motor/Sensory dysfunction
- Patients health and age
- Problems at adjust joints
- Soft tissue problems